Artificial Muscles: Actuators for Lower Limb Prostheses

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Introduction

Prosthetic clinical experience indicates many veterans suffer from lack of endurance, non-symmetrical gait, and high levels of effort while simply walking at their self-selected pace. The integration of an artificial musculo-tendon actuator into a below-knee prosthesis has the potential to greatly improve amputee gait by providing the missing propulsive force of the ankle musculature.

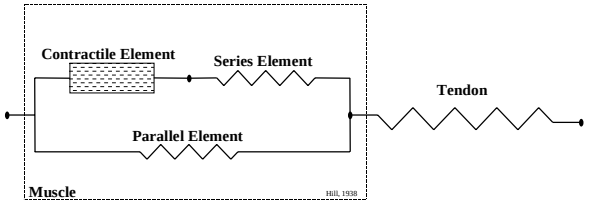
Objective

Our objective is to test the hypotheses that a powered prosthetic limb will reduce the metabolic cost of locomotion, reduce the perceived level of effort, and improve gait symmetry as measured by kinematic and kinetic techniques when compared to conventional prosthetic limbs. Our intermediate objective is to develop an artificial muscle and tendon whose performance mimics that of the *triceps surae* muscle group and Achilles tendon during walking, while remaining suitable for use on a prosthetic limb.

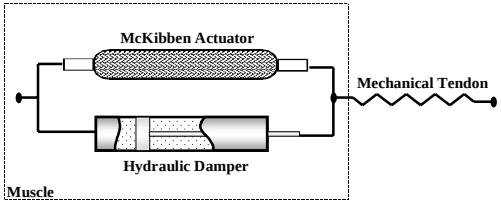
Methods

Using published data, we developed a Hill-based model of skeletal muscle and an energy storage model of tendon to create performance specifications for an isolated, whole muscle-tendon system. These specifications were used as design criteria for an artificial musculo-tendon actuator, developed with the aid of computer simulations (finite element, fluid, and lumped parameter). The simulation results indicate the predicted output force of the proposed design would meet or exceed the forces necessary for amputee walking. We proceeded with fabricating the device using McKibben actuators as contractile elements. To test its performance, we used a Bionix™ testing instrument (MTS Systems Corp., Minnesota, U.S.A.) to measure the output force for various velocity and activation profiles enveloped by the maximum conditions expected during locomotion.

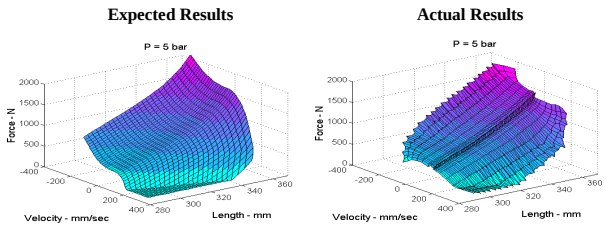
Skeletal Muscle-Tendon Model



Artificial Muscle-Tendon

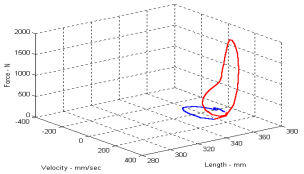


Artificial Muscle-Tendon Performance



Results

Under isometric conditions, the maximum force achieved was 1600 N. During eccentric (lengthening) contractions, the output force increased with velocity and was greater than 2000 N at the maximum velocity of 300 mm/s. During concentric (shortening) contractions, the output force decreased with velocity, asymptotically approaching zero at the maximum velocity condition. The resulting three-dimensional plots of the force-length-velocity relationships, shown in the lower cente panel, are similar to the *triceps surae* and Achilles tendon model predictions.



Prosthetic Walking

The figure above gives the model-predicted force-length-velocity profile for the artificial muscle-tendon during normal walking (blue=swing, red=stance). The experimental performance of the artificial muscle-tendon envelopes this profile, indicating the artificial system can provide the necessary and sufficient forces for normal walking.

Conclusions

We have successfully developed an artificial musculo-tendon actuator that mimics the function of the *triceps surae* and Achilles tendon. We are currently developing a robust control system and are planning human subject tests with an integrated, powered prosthesis for lower-limb patients. By providing appropriate propulsive forces during walking, we hope to improve amputee gait as indicated by the metabolic cost of locomotion, the perceived level of effort, and gait symmetry.

Further Information

http://rehabctr.vamc.washington.edu/prosthetics

Funding Acknowledgement

The Department of Veterans Affairs, Veterans Health Administration, Rehabilitation Research and Development Service, project number A0806C, supported the research reported here.